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ABSTRACT

The objectives of this exploratory study were to determine: (1) the approach to learning of physics students (N=142) at John Abbott College (Quebec, Canada) as determined by the Study Process Questionnaire; (2) the intellectual demands of quizzes, tests, and final exams in physics using a scheme derived from Bloom's taxonomy; and (3) the relationships between the approach to learning, the intellectual demands of assessment, and the performance of the students. The findings show that most incoming physics students approach physics with the intention of memorizing formulae rather than understanding concepts. They adopt surface or surface-achieving approaches. In examining the intellectual demands of the quizzes, tests and final examinations it was found that the majority (70%) of items required routine problem solving, while 28% required comprehension. The grade assigned to items requiring comprehension increased from Mechanics 101 (19%) to Electricity and Magnetism 201 (28%) to Waves and Optics 301 (32%). This approach to learning adopted by students was found to be related to the intellectual demands of the examinations, to the students' performances on the final examination, and to their prior knowledge of the concept of force. (Author/JRH)

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Approach to Learning and Assessment in Physics

Leslie Dickie

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Approach to Learning and Assessment in Physics

Leslie Dickie

September 1994

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Abstract

The objectives of this exploratory study were to determine: 1) The approach to learning of physics students at John Abbott College as determined by the Study Process Questionnaire, 2) the intellectual demands of quizzes, tests and final exams in physics using a scheme derived from Bloom's taxonomy, and 3) the relationships between the approach to learning, the intellectual demands of assessment, and the performance of the students.

The students in the study wrote the Study Process Questionnaire and the Force Concept Inventory in Mechanics 101 classes at the start of the 1993 fall semester. Students who proceeded to Electricity and Magnetism 201 re-wrote the measures at the end of their second semester.

The findings show that most incoming Physics students approach Physics with the intention of memorizing formulae rather than understanding concepts. They adopt surface or surface-achieving approaches. After two semesters the achieving approach had decreased while the surface motivation had increased and there was a trend for the deep motivation to decrease.

In examining the intellectual demands of the quizzes, tests and final examinations it was found that the majority (70%) of items required routine problem solving, while 28% required comprehension. The grade assigned to items requiring comprehension increased from Mechanics 101 (19%) to Electricity and Magnetism 201 (28%) to Waves and Optics 301 (32%).

The approach to learning adopted by students was found to be related to the intellectual demands of the examinations, to the students' performances on the final examinations, and to their prior knowledge of the concept of force.

Résumé

Cette étude exploratoire avait pour objet de déterminer: 1) comment les étudiants au Collège John Abbott abordent l'apprentissage de la physique à l'aide du "Study Process Questionnaire", 2) les exigences intellectuelles que posent les examens modulaires et les examens de synthèse basés sur la taxonomie de Bloom, et 3) les relations qui existent entre l'approche cognitive, les exigences intellectuelles de l'évaluation et la performance des étudiants.

Les étudiants ayant participé au projet ont répondu au "Study Process Questionnaire" et au "Force Concept Inventory" qui leur ont été soumis au début du semestre d'automne 1993 durant le cours de Mécanique 101. Les étudiants ayant réussi ce cours et s'étant inscrits au cours d'Electricité et Magnétisme 201 ont répondu aux mêmes questions à la fin du second semestre.

Nos résultats montrent que la plupart des étudiants qui commencent en physique abordent l'étude de cette discipline avec l'intention de mémoriser les formules plutôt que d'essayer de saisir les concepts. Ils préfèrent une approche superficielle ou une approche superficielle de réalisation. Nous avons constaté qu'après deux semestres, l'approche de réalisation a diminué tandis que la motivation superficielle a augmenté et qu'enfin une tendance décroissante se manifeste pour la motivation profonde.

En examinant les exigences intellectuelles demandées aux examens modulaires et aux examens de synthèse, nous avons découvert que 70 % des questions n'exigeaient que de l'habileté à résoudre des problèmes de façon routinière tandis que 28 % exigeaient de la compréhension. La cote attribuée aux questions exigeant de la compréhension a augmenté de 19% durant le cours de Mécanique 101, à 28% durant le cours d'Electricité et Magnétisme 201 et enfin à 32% durant le cours d'Optique et Ondes 301.

Nous avons trouvé que la façon d'aborder l'étude de la physique était reliée aux exigences intellectuelles demandées aux examens, aux résultats obtenus aux examens de synthèse ainsi qu'aux connaissances antérieures sur le concept de force.

CHAPTER 1

Approach To Learning And Assessment In Physics

1.0 Introduction

One of the most important and controversial issues in contemporary education is that of assessment: the assessment of student learning and the impact of assessment on student learning. When students enter their classrooms, they look to the teacher for guidance about what to learn and how to learn and, rightly or wrongly, they see the tests and other assessments as indicators of what the teachers consider to be important. The influence of final examinations is great. Indeed the primary concern voiced by most students facing a learning task is. "Is this going to be on the test?" After reviewing over 200 studies of the impact of classroom evaluation, Crooks (1988) concluded that assessment guided the student's judgment of *what* it was important to learn, and affected their motivation and approach to studying; that is the *how* of their approach to the learning task. If the test focuses on factual knowledge, the student will learn to memorize; if the test requires analytical thinking the student will learn to reason analytically. Over twenty five years ago Rogers (1969), in speaking about learning physics, pointed out that learning will be sabotaged if the final exam asks for numbers to be put in memorized formulae even if the classes were dynamic,

complemented by intriguing experiments and were accompanied by forceful exhortations to understand the physics. The intellectual skills the students rehearse will depend on the cognitive demands of the tasks they are asked to undertake.

Once the teachers' expectations have been communicated the students can decide if they want to study and what learning strategies they want to use. The combination of strategy and motivation is called the *approach to learning* of the student. Three approaches have been identified; surface, deep, and achieving (Ramsden, 1991). In a surface approach the student focuses on memorizing to obtain a passing grade, a deep approach involves an intention to understand the material, while in an achieving approach a student adopts deep or surface level strategies according to what he or she judges to be most efficient for obtaining grades (Biggs, 1987). While students can control the approach to learning, they are just a part of a larger system. The boundaries of the system are set in part by the institution, in part by the participants' perceptions of one another, and in part by the habits and practices of both teacher and student (Bhushan, 1991; Brekelmans, Wubbels, and Créton, 1990; Roth 1994). Within these boundaries are many complex interactions that influence the quality of learning: one of these is the interaction between the student's motives and strategies and the assessment practices of the teacher.

1.1 Statement Of The Problem

The purpose of the present study was threefold: first to determine the approach to learning of students in physics classes, as measured by the Study Process Questionnaire (Biggs, 1987); second to determine the intellectual demands of final examinations, tests, and quizzes in physics, using a scheme

based on Bloom's Taxonomy (Bloom, 1956); and third to search for relationships between these two variables, as well as the impact on the performance and persistence of the student. The performance of the students was measured by their grades in the physics final exams, and by their understanding of the concept of force as measured by their score on the Force Concept Inventory (Hestenes, Wells, and Swackhamer, 1992).

Three questions were asked:-

1 What is the approach to learning, as assessed by the Study Process Questionnaire, of students studying physics at John Abbott College?

2 What are the intellectual demands of final examinations, tests, and quizzes, in physics at John Abbott College?

3 Are there relationships between the intellectual demands of the exam, performance on the exam, and the learning approach of the student?

1.2 Review Of The Literature

1.20 Persistence And Attrition

In Quebec, 47% of those between 17 and 19 years old attend Cégep and of these only 19% choose to study science. At John Abbott College more than the provincial average of entering students choose science (27% vs. 19%)

(John Abbott College Registrar's statistics for 1991; Ducharme, 1989; Noel, 1988; Conseil des Collèges, 1988). For those who entered science at John Abbott in the fall of 1986 Boisset, MacKenzie, and Sidorenko (1989) found that after four semesters 55% of students had persisted, 25% had transferred to other programs, and 21% had left the college. Many students do not feel that they have control over their learning environment in Cégep, and frequently blame their own failure on factors that they consider to be beyond their control (Dweck and Elliott, 1983). Even students who do persist and succeed frequently do not see themselves as controlling their own fate. Indeed Boisset, MacKenzie, and Sidorenko (1989) found that only about a third of the students in their sample felt they had much control over what happened to them. Their study did find a gender difference in the overall rate at which students transferred out of science in that there was a tendency for females to attribute their lack of success to intrinsic factors that they could control, whereas males tended to attribute their failure more to extrinsic factors. Davis and Steiger (1993) found that one of the most reported reasons for dropping out of science at Cégep was loneliness, compounded by the emphasis on silent listening to teacher talk and solitary work doing calculations.

1.21. Approach To Studying And Learning

While it is true that students can control the length of time and amount of effort they may devote to the learning task, students may adopt varying study approaches when faced with a particular task because they enter college with motives and intentions that do not match the college's learning

environments: they may have different perceptions of the teacher, the task, and the college.

An *approach* to learning describes the relation between the student and the learning he or she is doing. It has elements of the student's motivation and elements of the student's perceptions in it. For example, a student may learn in order to obtain the diploma he or she wants, or they may be interested in a topic and want to find out more; they may be seeking to avoid pressure from a parent or they may be seeking status or recognition. An approach to learning is not an ability a student has, it is a combination of motivation and strategy, and as such must be distinguished from a *learning style* which refers to how the student structures their learning activities, and is not sensitive to context (Schmeck, 1988).

Distinctions have been made in the research literature between three approaches: surface, deep, and achieving (Biggs, 1993; Entwistle, Hanley, & Hounsell, 1979; Marton and Säljö, 1976, 1984; Ramsden, 1985).

In the *surface* approach the motivation is external: school is a means to an end. Students adopting this approach need to balance avoiding failure against working too hard. The strategy is to focus on memorizing or applying procedures unreflectively, rote learning.

In contrast, students who use the deep approach will be motivated by personal curiosity. They will read widely, discuss, reflect on the material, focus on relations between parts, the structure of the problem as a whole, and the application of theory to real problems (Ramsden, 1991).

The *achieving* approach is somewhat of an amalgam of *deep* and *surface* . The student adopts deep or surface level strategies according to what he or she judges to be most efficient for obtaining grades. This approach is based on a particular form of extrinsic motive: the ego-enhancement that

comes from visibly achieving (Biggs, 1987). The student allots time and effort to tasks, using study skills such as planning, being neat and self-disciplined, in accord with the perceived contribution of the task to a high grade. The relationships between the strategies and motives is conveniently displayed in a figure: Figure 1.1.

Figure 1.1
Approaches to Learning

Approach	Motive	Strategy
Surface	Surface motive (SM). is instrumental: main purpose is to meet requirements minimally: a balance between working too hard and failing	Surface Strategy (SS) is reproductive: limit target to bare essentials and reproduce through rote learning
Deep	Deep Motive(DM) is intrinsic: study to actualize interest and competence in particular subject	Deep Strategy(DS) is meaningful: read widely, connect with previous relevant knowledge.
Achieving	Achieving Motive(AM) is based on competition and ego enhancement: obtain highest grades whether or not material is interesting	Achieving Strategy(AS) is based on organizing ones time and working space: behave as a model student.

The approach adopted by a student is determined by the task and the student's perception of the situational demands of the teaching and testing (Ramsden, 1988). The learning that results from the different approaches has been shown to depend on the approach adopted, the academic motivation of the student, the student perception of the learning climate, and what the

examiner rewards (Biggs, 1978, 1989; Craik and Lockhart, 1972; Svensson, 1977).

Deep learners appear to perform as well as surface learners on low level, or surface, tasks, and do much better on higher level tasks. In physics Prosser and Millar (1989), in a study of approach-outcomes of first year students found a strong connection between a deep approach and the abandonment of an Aristotelian view of mechanics in favour of a Newtonian view. Students also differ substantially in their capacity to clearly identify the nature and substance of the task demands; they may be able to correctly identify the hidden demands of the task but be unable to adapt to its demands (Marton & Säljö, 1976).

There have been different methodologies used in assessing a student's approach to learning. Marton and Säljö (1976) interviewed students as they undertook a reading task and subsequently described the qualitatively different learning outcomes using (and introducing) the terms deep and surface. Johansson, Marton, and Svensson, (1985), and Prosser and Millar (1989) interviewed students as they undertook a series of conceptual tasks in physics and from an analysis of the transcripts established the student's learning approach. The Study Process Questionnaire or SPQ was developed by Biggs (1987) to assess approach to learning of college and university students. Biggs (1993) has reviewed the development of the instrument and the ways in which psychometric techniques such as factor analysis, information processing theories, and contextually based work on student approaches to learning have contributed to the development and understanding of both the instrument and the constructs it utilizes. The questionnaire has been used by Biggs and others (e.g. Beckwith, 1991; Biggs, 1987; Eley, 1992; Hegarty-Hazel & Prosser, 1991) in a variety of settings and

disciplines. The validity of the constructs of the instrument have been confirmed using populations of high school, community college, and university students in Australia, and while test-retest reliability is not necessarily an appropriate index for an instrument that can be used to track changes in student characteristics, none-the-less stability has been demonstrated (Biggs, 1987).

1.22 Prior Knowledge And Understanding Of The Concept Of Force

Years of experience give every student in introductory physics a well-established system of commonsense beliefs about how the world works. Many previous studies have compared this prior knowledge with the views of expert physicists (Clement, 1982; Halloun and Hestenes, 1985; McDermott, 1984; Viennot, 1979), and it has been established that students' commonsense views are frequently incompatible with Newtonian concepts, (hence the label "misconceptions"), and that conventional instruction does little to change these beliefs (Hake, 1994). The Force Concept Inventory (Hestenes, Wells & Swackhamer, 1992) was developed from the earlier Mechanics Diagnostic Test (Halloun and Hestenes, 1985) to determine students' understanding of the concept of force. The test-retest reliability and validity of both the Diagnostic and the Inventory have been established by the authors using populations of high school, college, and university students in settings as diverse as high school in Arizona and first year physics classes at Harvard. In Québec Desautels (1985) and Dickie (1988) have shown that students at both a francophone (Rosemont) and an anglophone (John Abbott) Cégep have a poor understanding of the concepts of mechanics in agreement with the findings in other countries such as France, New Zealand, and the United

States (Halloun & Hestenes, 1985; Hestenes, Wells & Swackhamer, 1992; Osborne & Freyberg, 1985; Viennot, 1979). Hegarty-Hazel & Prosser (1991) have shown that prior knowledge affects the adoption of study strategies and influences post knowledge. The authors of the Inventory have remarked on the importance of the attitude and motivation of students in overcoming misconceptions about force, and also the tendency of teachers to avoid "hard" conceptual questions in favour of quantitative problems where the answer is a number obtained by substitution into a formula after some algebraic manipulation.

1.23. Assessment In Physics

At John Abbott College, as at many other colleges and universities, a typical physics course will have a final examination, one or two mid-term tests, and possibly a number of quizzes and assignments. Most institutions have available in their library files of old examinations which students consult when preparing for an exam. While the course syllabus provides an overview of a course most students will have a better understanding of the aims and methodologies of a teacher after the first test. It has long been accepted (Michels, Sears, Verbrugge and Palmer, 1957; Fowler, 1969) that physics teaching at the college level should accomplish two goals; 1) an understanding of a core of knowledge, and 2) the systematic development of the methodology of physics. The requirements for physics tests to achieve these aims have been reviewed by a number of authors who have proposed different schemes to ensure that both aims are met (Aubrecht, 1990; Aubrecht and Aubrecht, 1983; Ferris, 1960; Fowler, 1969; Kruglak, 1966). For example Kruglak (1966) has suggested the use of a check-off grid to ensure that a test

contains items that test 1) the recall of facts, 2) the use of applications that use these facts, and 3) the ability to apply principles to novel situations. Over time, there has been a shift in thinking about the relationship between teacher and student. In the past, the teacher was considered to be the dispenser of knowledge while the student was the passive listener. This viewpoint has shifted to that of the teacher as the guide and the student as the decision maker and constructor of knowledge (Gallagher, 1994; White, 1992). This shift in viewpoint has changed the emphasis between process and content but not the need to assess both.

1.24. Thinking Skills In Physics

Research on student perceptions and motivation suggests that students do not focus on the content goals of school work but implicitly ask: What do I have to do? How do I have to do it? Can I do it? Do I want to do it? (Blumenfeld, Mergendoller, and Swarthout, 1987). What abilities and skills do physics students need to answer these questions for themselves? Do physics teachers see answering these questions as goals for their instruction? College science teachers identify a variety of objectives for their courses One study asked 200 physics professors at both two year and four year colleges to identify the abilities that they valued most in their students: they found that visualization, facility with mathematics, logic, and problem solving were most valued (Peltzer, 1988). On a more general level cognitive research on science teaching shows the importance of four different types of learning: 1) subject matter learning; 2) knowledge of principles, rules, and specific situational knowledge; 3) learning strategies: and 4) metacognitive learning (Wittrock, 1994). After interviews with students and professors at

universities in Quebec and elsewhere Donald (1992) has described the thinking skills valued and developed in higher education. The levels of her model are: description, selection, representation, inference, synthesis, and verification. Donald found that physics professors believed that these skills were developed by problem solving (Donald, 1993).

Despite the beliefs of many physics professors in the appropriateness of problem solving as both a teaching and assessment methodology (Aubrecht, 1990; Van Heuvelen, 1991), it has been pointed out by McDermott (1991) that there is no convincing evidence that reasoning ability improves as students work the standard problems in an introductory physics course. In the Cégeps, problem solving in the form of assignments, problem sessions, tests, quizzes, and final exams is predominant in physics teaching. Supporting the wide acceptance within the physics community of problem solving as both a teaching and an assessment methodology is a large body of literature concerned with identifying and comparing the ways in which students approach problem solving (Clement, 1982; Fuller, 1982; Heller and Reif, 1984; Larkin, 1983; Zajchowski and Martin, 1993), or comparing the performance of novices with that of experts (Champagne, Gunstone, & Klopfer, 1985; Chi, Feltovich & Glaser, 1981; Larkin, 1983). Ferguson-Hessler and de Jong (1987) have pointed out that for successful problem solving in physics students must not only possess a knowledge structure made up of 1) subject matter knowledge (both declarative and procedural), 2) knowledge of strategy, and 3) knowledge of the problem situation, but must be able to access and apply this knowledge structure. Reif, Larkin, and Brackett (1976) in an analysis of what prerequisite abilities a student needed in order to use a relation for solving physics problems defined "understanding a relation" in terms of four categories of abilities; 1) statement and example, 2) quantities in the relation

(vector/number, sign, units, ...), 3) the relation itself (applicability, dependence, comparison, ...), and 4) organization of the relation (when and where to apply).

If problem solving is to be used to measure the thinking skills and degree of understanding of physics principles achieved by students it must be recognized that students generally approach problems according to their surface features, such as the presence of an inclined plane, rather than the underlying physical principles, such as the conservation of momentum or energy (Chi, Feltovich and Glaser, 1981). While it has been shown that problems that are unfamiliar to the solver but are structurally similar to familiar ones can be used to measure understanding (Gagné and White, 1978; Mayer, 1974), when physics test questions that cannot be solved by superficial application of a problem solving algorithm are asked, performance drops significantly (Halloun and Hestenes, 1985).

1.25. Classifying The Intellectual Demands Of Learning Tasks In Physics

The intellectual demands of a learning task in physics are defined by the answers students are required to produce and the routes that can be used to attain these answers (Doyle, 1983). In undertaking an analysis of the intellectual demands of the learning tasks, one is not looking at the physics content that is being asked for but at the behaviours and processes that are being required. This breakdown is necessary in order to apply the constructs of psychology to the demands of the tasks (Resnick, 1976).

In an exploratory study, Klatt (1991) hypothesized that because many physics problems require the student to construct a diagram from a verbal

description, the student is engaged in visualization and geometrical thought. His study analyzed the implicit geometrical content of problems from the kinematics and dynamics units of the Ontario Academic Course program using the classification scheme of van Hiele (1986).

Another way to conceptualize the reasoning skills that students bring to bear on a problem is their information processing ability; that is the limit of the number of different ideas or schemes students can hold in their working memory at one time. Pascual-Leone defined this limit as the usable M-space (Pascual-Leone, Goodman, Ammon, & Subelman, 1978), and the demand of a problem as the M-demand. Niaz (1993a, 1993b) has reviewed the role of Neo-Piagetian theory and the effects of M-space and M-demand on problem solving in science. In chemistry Johnstone and El-Banna (1986) have pointed out the usefulness of mental capacity, or M-space, as a predictor of performance in chemistry exams, while Niaz has examined the relation between the M-demand of chemistry problems, the M-capacity of students, and student performance on solving chemistry problems (Niaz, 1987, 1988). In physics Roth (1987, 1990, 1991) has examined the influence of M-space on the amount of practice needed to induce problem solving strategies in physics.

Aubrecht (1990) used a different classification scheme of the intellectual demands of physics exams based on three broad categories of logical processes (recall, interpret, apply), while Ferris (1960) used a scheme based on Bloom's taxonomy (Bloom 1956). In an analysis of first year final exams in a number of different subjects, including physics, Crooks and Collins (1986) used three categories, 1) straightforward recall, 2) straightforward application of formulae or principles; comprehension, and 3) analysis, synthesis, evaluation, solution of novel problems.

1.26 Taxonomies Of Intellectual Demands

There have been a number of descriptive frameworks offered to classify and identify the intellectual demands of objectives and/or assessment items (Biggs, 1991; Donald, 1985; Gagne, 1977; Merrill and Tennyson, 1977). However the most widely used classification scheme is that developed some forty years ago at the University of Chicago by a team under the editorship of Benjamin Bloom (1956). The *"Taxonomy of Educational Objectives, The Classification of Educational goals, Handbook I: Cognitive Domain"* or *"Blooms Taxonomy"* as it is widely called, was developed in part to assess the demands of course objectives, and in part to examine the demands of examinations. It was developed in a pragmatic fashion from the ideas of several working groups and has come to be widely accepted. The six main levels of the taxonomy, which are hierarchical, are 1) Knowledge - recalling information much as it was learned, 2) Comprehension - reporting information in a way other than how it was learned to show that it has been understood, 3) Application - use of learned information to solve a problem, 4) Analysis - taking learned information apart, 5) Synthesis - creating something new based on some criteria, and 6) Evaluation - use of criteria in judging the value of something for a particular task or program.

As part of a recent "Forty year retrospective" Krathwohl (1994), one of the original editors, suggested that the framework of the taxonomy has been most useful as it has been modified to better fit the discipline and the purpose to which it has been being applied. While no single taxonomy can be expected to apply equally well to a variety of disciplines because of the diverse nature of learning in different disciplines (Furst 1981), Bloom's taxonomy is

widely accepted in the literature, and has been applied to many disciplines in numerous cultures. In the Cégeps Bateman (1992) used the taxonomy to examine the intellectual demands posed by some 2300 assessment items taken from 27 social science courses of six Cégeps.

Since problem solving is so important to physics, it is pertinent to review how Bloom treats problem solving. Problem solving can be classified at either the Comprehension or the Application level. The distinction between the two classifications is predicated on the assumption "If a student really comprehends something they can use it." Comprehension as Bloom uses the term implies a student can use an abstraction (formula, principle) when its use is specified. Application requires that a student correctly use an abstraction when no mode of solution is specified and the student must deduce the appropriate abstraction from the context of the problem. The process is illustrated by the chart of Figure 1.2 (Bloom, 1956, p. 121). Confounding this classification of solving a problem into either comprehension or application is the question of rehearsal. The objective in Application is to embody the idea of transfer of training: i.e. the application in a new situation of what has been learned in a different area (p. 123). Is the problem of a familiar type? If the problem is not novel, if the student "merely has to recall the situation in which he [or she] learned the abstraction" (p. 125) the item is at the Comprehension level.

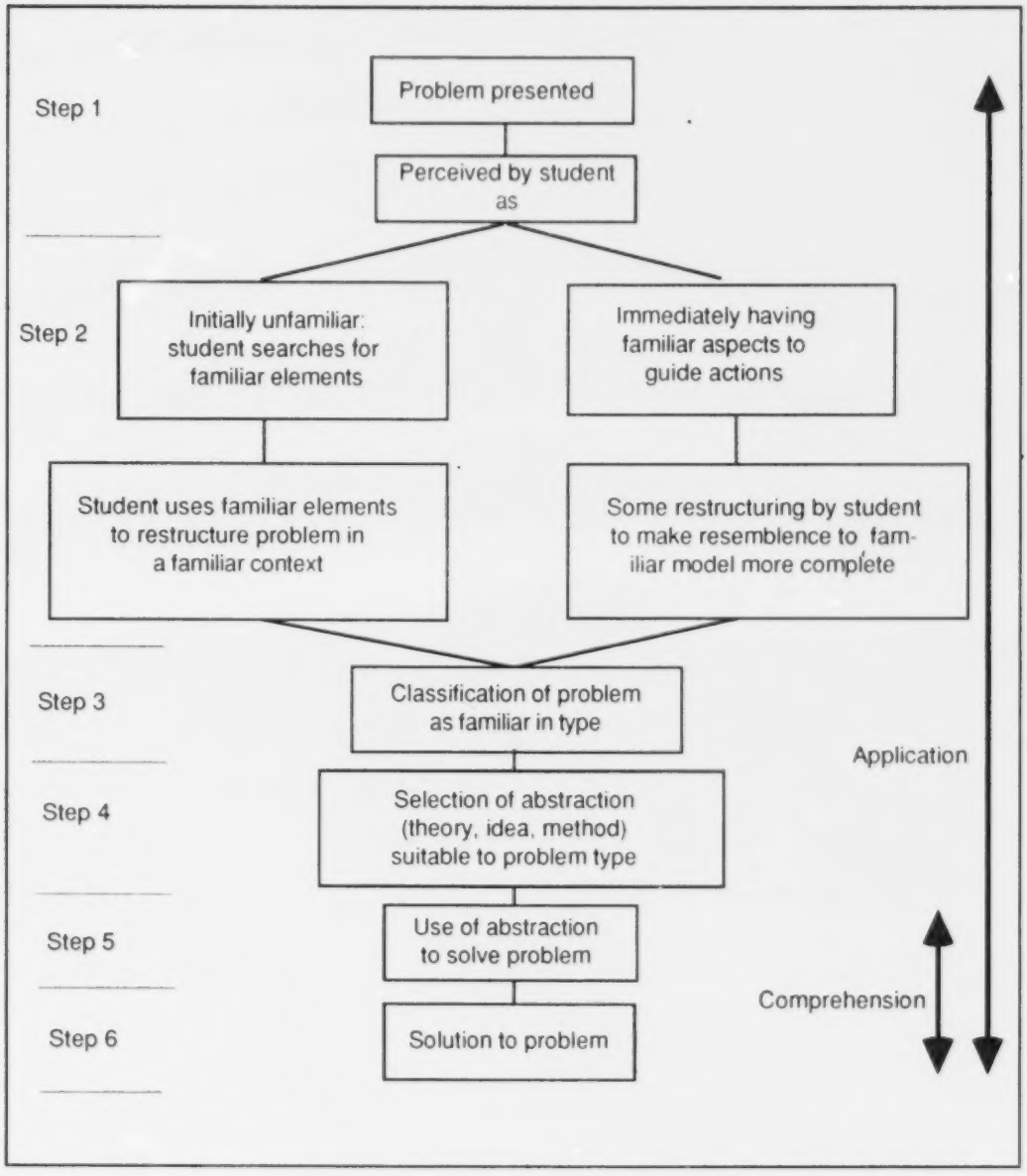
McGuire (1963), in modifying Bloom's taxonomy to better fit assessment in medicine, replaced Comprehension, Application, and Analysis with Generalization, Problem Solving of a routine type, and Problem Solving of an unfamiliar type. Simple interpretation of data was included with problem solving of a familiar type, while data analysis was included with problem solving. She also inverted the order of Evaluation and Synthesis.

In a review of the intrinsic nature of academic work as it is experienced by students in the classroom, and the ways in which the intellectual demands of that work are related to academic success (Doyle, 1983), identified four general types of academic tasks; 1) memory tasks where the student is expected to reproduce information previously encountered, 2) procedural tasks, where the student is expected to apply a predictable formula or algorithm, 3) comprehension tasks, where the student is expected to recognize transformed information, draw inferences, and apply procedures to new problems, and 4) opinion tasks where students are expected to state a preference. He was interested in the actions of students after they were presented with a task, i.e. what the tasks lead the student to do, and the ways in which the tasks lead to learning. The classification was based upon the general categories of cognitive operations that are involved in task accomplishment (Greeno, 1976).

The relevance of Doyle's work to classifying physics exam questions is that it explicitly adds consideration of the procedural complexity of a task to that of cognitive complexity. He explicitly recognizes the routine nature of applying a memorized formula by defining Procedural Tasks as those requiring students to apply a standardized and predictable formula or algorithm to generate answers. He contrasts Procedural and Comprehension tasks by pointing out the distinction between knowing how to apply an algorithm and knowing why the algorithm works and when it should be used.

Figure 1.2

The problem-solving process in answering questions in the "Application" category. (Bloom, 1956, p. 121)


Step 1
Problem presented
Perceived by student as
Step 2
Initially unfamiliar: student searches for familiar elements
Immediately having familiar aspects to guide actions
Student uses familiar elements to restructure problem in a familiar context
Some restructuring by student to make resemblence to familiar model more complete
Step 3
Classification of problem as familiar in type
Step 4
Selection of abstraction (theory, idea, method) suitable to problem type
Step 5
Use of abstraction to solve problem
Step 6
Solution to problem
Application
Comprehension

Recently Lawrence at the University of Michigan has integrated and refined the taxonomies of Bloom and Doyle to arrive at a hierarchy that differs from both (Lawrence, Hart, Kingan, and Campbell, 1994). Her group was lead to develop the "Michigan" scheme as a part of a project to examine the equivalencies of courses given at two year colleges to those given at four year colleges. In assessing the demands and equivalencies of courses at different institutions, this work stresses the influence of all aspects of the academic task both in the classroom and outside it, and the importance given by the instructor to different tasks and approaches. The taxonomy has different forms for different disciplines. The Michigan scheme for Calculus recognizes the rote or algorithmic nature of routine formula substitutions and it further recognizes that some problems require students to make choices about which rule or formula to apply based on the information given in the problem. These decisions are a part of the Comprehension levels of Bloom and of Doyle. In inserting a new level, Procedural/Comprehension, before Comprehension, the problem solving process is further split off from Comprehension and placed before it. This is in agreement with discussions held with physics teachers at a number of Cégeps, and with others familiar with both the use of Bloom's taxonomy and the nature of the learning task in physics. There remains the problem of where to place novel problems that require a student to apply known methods to unfamiliar situations.

1.3 Purpose Of The Study

This was an exploratory study designed to determine the intellectual demands of Cégep physics exams. As such while it was predicted that most exams would be of a problem solving nature, no predictions were made as to

the cognitive level of the exam items. However previous work on school science textbook tests and standardized tests has shown that more than 75% of the items tested recall of facts and routine applications (Garcia and Pearson, 1994). Similarly in her study of assessment in the Social Science programs of the English language cégeps, Bateman (1992) found that more than 80% of assessment items were at the Knowledge or Comprehension levels. Crooks and Collins (1986) in a study of the skills first year university students were required to demonstrate in the final examinations of twelve different subjects, including physics, found that the most common level was that requiring the straightforward application of formulae together with comprehension as defined by Bloom.

The second part of the study was to determine the approach to learning of students studying physics and to explore relationships between the student's approach and their learning outcomes as measured by grades in the courses and exams, and the cognitive demands of those exams.

1.4 Significance Of The Study

Not just in Quebec, but worldwide, the learning outcomes expected of colleges are being changed from specifying content to specifying the development of abilities. The importance of seeing the connection between assessment and the kinds of learning that students achieve is not a new issue but it has become more important with the current emphasis on accountability, both financial and intellectual. The learning outcomes are determined by the tasks and activities students undertake.

If assessment encourages the memorization and recall of isolated pieces of information, students will be ill-equipped to adapt to new needs

throughout their lifetimes because of the rapid obsolescence of factual information. It follows that the knowledge that students accumulate during schooling is less important than the learning skills and habits they develop. If assessment encourages meaningful application and understanding of methods and principles, and both teachers and students share an understanding of the outcomes of the teaching learning/process (Solas, 1992), students will be better able to cope with the changing demands and challenges they will encounter. The role of exams in directing and shaping the work of both students and teachers is pivotal: not only can the examinations encourage meaningful learning but they can foster teaching that rewards appropriate learning.

CHAPTER 2

Methodology

2.0 Introduction

This study is in two parts: 1) the learning approach of physics students, and 2) the cognitive demands of exams in physics. This chapter describes the subjects and measures used in the first part of the study then describes the development of the taxonomy used in the second part.

2.1 Sample

The first sample for the study consisted of 107 first semester students who completed the measures detailed below at the start of the year, followed Mechanics 101 and wrote the final exam. The second sample consisted of the 35 students who, after passing Mechanics 101, entered Electricity and Magnetism 201, wrote the final exam in the course, and repeated the measures at the end of the year.

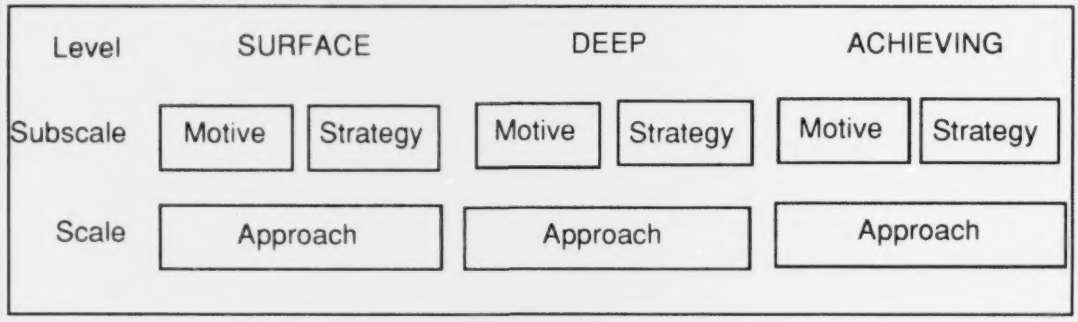
2.2 Measures

2.21 Study Process Questionnaire

The Study Process Questionnaire (SPQ) is a 42-item group administered instrument. Each item consists of an affirmative self-report statement that describes a student's strategy or motive. An example of a motive statement is " I find that at times studying gives me a sense of deep personal satisfaction." An example of a strategy statement is "I summarize suggested readings and include these as part of my notes on a topic." After consultations with students and teachers the wording of the questionnaire was changed to better conform to common usage in the Cégeps (e.g. tertiary to post secondary, lecturer to teacher, rote to learn by heart, ...). For each item of the questionnaire the student responds on a five point Likert scale: 1 - this item is never or only rarely true of me, 2 - this item is sometimes true of me, 3 - this item is true for me about half the time, 4 - this item is frequently true of me, and 5 - this item is always or almost always true of me. Seven items of the questionnaire are constructed to reflect each of the subscales: surface, deep, and achieving *motivation*, and seven items to reflect each of surface, deep, and achieving *strategy*. The subscales are further combined to give the scale scores; Deep Approach, obtained by adding the two deep sub-scale scores (DM+DS), and similarly the Surface Approach (SM+SS), and Achieving Approach (AM+AS), scale scores. The relations between these scores is displayed in Figure 2.1.

Figure 2.1

SPQ Scale and Sub-scale scores



The scale scores were used as dependent variables to identify a student's approach to learning, and the sub-scale scores were used as independent variables to assess changes in the motives and strategies over the one year period of the project. A student's approach to learning was determined by combining the scale scores. A score below the thirtieth percentile was considered below average, while a score above the seventieth percentile was considered above average. Norms are available for male and female students in different faculties of universities and colleges of applied arts and sciences in Australia. Students in this study were in the first year of the pre-university science stream at Cégep, therefore results were analyzed using Biggs's norms for science university students.

2.22 The Force Concept Inventory

The Force Concept Inventory is a twenty nine item multiple choice questionnaire that was used to determine a students prior knowledge of the concept of *force* and the agreement between the student's understanding and

the Newtonian understanding (Hestenes, Wells, and Swackhamer, 1992). The score on the inventory was used in this study as a dependent variable. The questionnaire was administered at the start of the study to measure the students prior knowledge, and again one year later at the end of the study to those students who had continued in physics to measure the change in their understanding. Because the score on the test is a measure of the student's understanding of the concept of force rather than of their ability to apply formulae, connections between the student's score and the student's approach to learning were also sought.

2.23 Cote Finale

The Cote Finale (science) is a weighted average of a student's high school grades for Secondary IV and Secondary V. It is calculated for students who took high school in Quebec, is used in determining admission to the college. The cote finale was used as a measure of high school performance.

2.3 Coding Scheme For Assessment Items

Bloom's taxonomy has six hierarchical levels, knowledge, comprehension, application, analysis, synthesis, and evaluation. Preliminary work showed that the examinations and other assessment items of this study involved the three lowest levels of Bloom's taxonomy but that the definitions of these levels did not adequately represent the intellectual demands of assessment items in physics. Given the predominance of problem solving as both a teaching and an assessment methodology in physics, it was necessary to consider the place of problem solving in the taxonomy and in particular two

linked issues; novelty versus rehearsal, and rote application of an algorithm versus understanding. The issue of whether a problem was novel was addressed by examining quizzes and tests which confirmed the initial hypothesis that almost all problem types were rehearsed. Indeed one could ask; Should a novel problem be part of a final exam in physics? The consensus of a number of physics teachers, at both John Abbott and other colleges, was that no, the final exam was not the place. The second issue was rote application versus understanding. When a student was applying a problem solving algorithm to the solution of a typical or "text-book type" problem, was the student reflecting on each step and understanding why choices were being made or were they just following a well worn path? A path that the student had seen demonstrated in class or had rehearsed as assignments were completed. The consensus of discussions with teachers was that it was generally the latter. Accordingly, it was decided to adopt the point of view of Doyle (1983), and of Lawrence et al (1994) and place Comprehension after routine problem solving. This is some-what at odds with Bloom's statement "If a student really comprehends something he can apply it" (1956, p. 120) because it accepts that the converse of this statement is not necessarily true. Deciding whether a student has understood a procedure could be resolved by interviewing the student, but examination of their correct written answer to a typical exam question is unlikely to reveal whether they were following an algorithm, or had an understanding of why the procedure was appropriate and successful.

The levels of the taxonomy used to analyze questions are given below. More complete definitions are given in Appendix 1.

Memory: Recalling information much as it was learned.

Procedural/Algorithmic: Following a routine series of steps in solving a problem. The problem is familiar and the rule or formula is either given in the problem or very familiar from previous rehearsal.

Procedural/Comprehension: Solving a problem that requires that choices be made about the which rule or formula to apply based on the information given in the problem.

Comprehension: Recognize transformed or paraphrased information. Draw inferences from previously encountered information. In applying a rule or formula demonstrate understanding of when, why, and how the relation can be applied.

The first category, Memory, demands the recognition or reproduction of information previously encountered. Bloom considers that such tasks do not require thinking and distinguishes this level from other intellectual tasks, tasks that require some content to act on. For example one does not just think, one thinks about projectile motion.

In physics there are many short, routine problems requiring little thinking or understanding. Bloom places such operations as part of knowledge but they are so common in physics that a separate category, Procedural/Algorithmic, is warranted. Similar distinctions in different disciplines have been made by Doyle (1983), Lawrence et al (1994), and McGuire (1963).

In the third category, Procedural/Comprehension, the student has to make choices, has to make decisions and judgments about what procedure to

follow, may even have to carry out some analysis or form an opinion - but at a straightforward level. The problem is not novel. In discussions with Cégep physics teachers it was agreed that placing this level before Comprehension was appropriate and proper, a decision also made by Lawrence et al, (1994).

The label Comprehension is used by Bloom, by Doyle, and by Lawrence to describe similar but slightly different levels of understanding. Bloom talks about transforming information to demonstrate that it has been understood and about applying a formula when its use is specified. Doyle defines it in terms of recognizing transformed information, and also in terms of choosing between several procedures in solving a problem. Lawrence talks about understanding the "gist" of a problem, the how and why procedures are used. In the present work the four categories of abilities defined by Reif, Larkin and Brackett (1976) as constituting understanding of a relation are used as the basis for the working definition of comprehension. These include the transformation abilities of Bloom or Doyle, for example translating from a table of values to a graph, or interpreting and using the information given in a graph. The understanding of why a problem solving procedure works places this after procedural/comprehension.

In adopting these levels, the cognitive demands of problems have been split into four levels: memory, rote application, those requiring limited comprehension, and those requiring understanding of principles rather than just the demonstration that an algorithm can be applied.

2.4 Procedures

2.41 Selection Of Sample.

The subjects for the study were science students taking Mechanics 101 in the fall 1993 semester at John Abbott College. The Study Process Questionnaire and the Force Concept Inventory were administered in six classes during the first two weeks of classes. There were both first and second year students in these classes because the fall semester of 1993 was one of transition to the "new" science program for the anglophone colleges. Of the 267 students who completed the SPQ, 153 were first year students, 88 were in their second year, and the remaining 26 were mature students. The Force Concept Inventory was administered in the second week of classes. Inevitably, there were students who wrote the first instrument but not the second and vice versa. The Cote Final (science) for the first semester students was obtained from the college.

Complete data was obtained for 111 students. At the end of the semester 107 of the students wrote the physics final exam. These 107 students constituted the main cohort in this study.

Of the 83 students who passed Mechanics 101, 52 enrolled in Electricity and Magnetism 201 and at the end of the second semester the 46 students who were still following the course were invited by letter and telephone to re-write the SPQ and the FCI. A $5.00 honorarium was paid upon completion of the questionnaires: Thirty-six accepted the invitation (78%), but one student did not subsequently write the 201 final exam. These 35 students constituted the second cohort in this study.

2.42 Determination Of The Approach To Learning

Using the norms provided by Biggs (1987) for university science students the scale scores were designated as *above average* if they were above the seventieth percentile, *average* if they were in the percentile range 31 to 70, and *below average* if they were below the thirtieth percentile. Following Biggs, a student was classified as adopting a predominantly Surface Approach if their surface scale score profile was greater than both of their deep and achieving profiles. In an analogous manner students adopting predominantly Deep or Achieving Approaches were identified. Biggs also considers two combined approaches, Surface Achieving and Deep Achieving. A student who had equal profiles for surface and achieving, and a lower profile for deep approach was classified as Surface-Achieving, while a student with equal deep and achieving profiles and a lower surface profile was classified as Deep-Achieving. In addition there were many students for whom a predominant approach did not emerge in that they were equal in deep and surface approaches and weaker in achieving.

2.43 Selection Of Quizzes, Tests, And Final Exams

The primary data for this part of the study were the final physics examinations Mechanics 101, Electricity and Magnetism 201, and Waves and Optics 301, given in December 1993 and May 1994 at John Abbott College together with a set of quizzes and tests for each course. Given that only a limited number of exams were examined it was decided to determine whether the assessment practices at John Abbott were representative. The final exams of physics 101, 201, and 301 given in December of 1993 were

obtained from five anglophone Cégeps. In the case of courses that did not give a final exam but used the grades from the term tests, these were obtained. Three of the colleges had a common marking scheme and common final exams. In the other two colleges teachers were free to set their own exam and grading policies. Structured discussions with teachers from the colleges showed that teachers exchanged tests and other assessments, and some compared average test marks and pass/fail rates to ensure uniformity across different sections of a course. At John Abbott the teachers of a course marked the common final exam collectively; i.e. one teacher would mark the first question in all scripts, another the second and so on. At another college a set of exams had been independently marked by four teachers and the grades assigned compared. In at least one college the same assignments were handed out to all students, and solutions posted in the hallways and were available in the library. The researcher and the two coders (who were experienced physics teachers from colleges other than John Abbott) reviewed all the exams and other assessment items and it was agreed that coding the assessments from John Abbott and the final exams/tests from two other colleges would give a representative picture of the practices at the five anglophone colleges. The assessments from the two colleges were selected because one had a policy of common final exams while one did not, and because the coders came from these colleges and could provide input as to the novelty or otherwise of the questions of the assessments. In all thirty quizzes, fifteen term tests, and ten final examinations totalling 710 items were coded.

2.44 Coding Of Items Of The Quizzes, Tests, And Final Exams

The process of assigning a final code to each question or part question (710 items) followed a number of steps. First, solutions to each question were prepared by the researcher. The majority of these solutions were annotated with the thinking processes that were followed. In making these annotations the researcher acted as an expert physicist trying to think like a novice. The construction of these solutions contributed to the development and understanding of the coding scheme. Second, after a training session, the coders were provided with a detailed rational for the coding scheme together with examples and two final exams were coded. The team then met to discuss the scheme and to compare codes. The coding scheme was adjusted and finalized. Then the coders and the researcher coded all 710 items independently.

The final codes were assigned as follows.

If the two coders agreed on the code this became the final code. The rate of agreement was 72%.

If there was no initial consensus the code assigned by the researcher was considered. If it agreed with one of the codes assigned by the coders this became the final code. This was the case for all but 16 cases. The remaining 16 items were discussed and final codes assigned. The chief cause of disagreement was between Memory and Comprehension. For example; was an electric field diagram, or the derivation of a simple harmonic motion formula, remembered or understood? In addition 5 items on which the coders agreed, but which one or the other had indicated they wanted to discuss, were also reconsidered.

In addition to being coded for intellectual demands each item was also classified according to the six different activities that the student had to undertake in answering the question. Each item was classified, 1) as a problem, 2) as requiring the construction or interpretation of a diagram, 3) as requiring the construction or interpretation of a graph, 4) as requiring a written response, 5) as requiring a derivation or proof, or 6) as being a multiple choice question.

2.5 Analysis Of The Data

The FCI and the SPQ responses were scored using Op-Scan sheets and the college computer system. In the case of the SPQ the raw data was transferred to a personal computer, and the sub-scale and scale scores computed with the help of a spreadsheet program (Excel). In exploring the relationships between the performance of the students on the final examinations and the measures, a variety of statistical tests were applied as appropriate; Anova, t-test, Tukey method of multiple comparisons, Pearson product-moment coefficients of correlation, and linear regression analysis (Glass and Hopkins, 1984). The statistical analysis of the results was done using SYSTAT.

CHAPTER 3

Approach To Learning

3.0 Introduction

This chapter describes the results of using the Study Process Questionnaire to identify the approach to learning of the students, and the changes in the sub-scale and scale scores over the two semesters of this study.

3.1 Approach To Learning Of Incoming Students

Within the cohort of 107 students who wrote the Study Process Questionnaire at the beginning of their first semester at the college, according to Biggs' norms 12% were classified as adopting a predominantly Surface Approach to learning, 5.6% Deep, 14% Achieving, 29% Surface Achieving, 12% Deep Achieving, and for 27% the approach was not identified because they were equally strong in both surface and deep and lower in an achieving approach. Results are shown in Table 3.1.

The results indicate that most incoming students show a Surface or a Surface Achieving Approach. The students wrote the instrument in their physics class, and were told to think about their physics courses when answering the questions. These students approach physics with the intention of

memorizing formulae rather than understanding concepts, and are prepared to modify their approach to do what they think will gain them marks.

Table 3.1

Percentage Of Incoming Students Classified As Adopting A Particular Learning Approach (n = 107)

Surface	Deep	Achieving	Surface-Achieving	Deep-Achieving	Un-determined
12	5.6	14	29	12	27

3.2 Approach To Learning After Two Semesters Of Instruction

Sixty three percent of the students who passed Mechanics 101 proceeded directly to Electricity and Magnetism 201. For the sample of these academically-on-track students who re-wrote the measures at the end of the second semester (35 or 78% of those who continued), there were increases in the percentages of students classified as adopting both a Surface and a Deep Approach, and declines in those adopting both an Achieving Approach, and the composite Deep-Achieving and Surface-Achieving Approaches. The findings show that after two semesters at Cégep the percentage of students classified as adopting a Deep Approach according to Biggs's norms has increased from 5% to 20%. Should we be satisfied when, after two semesters of physics, only 20% report that they try to understand the concepts of physics? The percentages of students classified as adopting each approach when the SPQ was written at the start of the first semester (pre), and at the end of the second semester (post) are shown in Table 3.2.

Table 3.2

Percentage Of Students Classified As Adopting A Particular Learning Approach: Cohort Of 35 Who Rewrote The SPQ At The End Of Their Second Semester

	Surface	Deep	Achieving	Surface Achieving	Deep Achieving	Un-determined
Pre	5.7	2.8	31.4	28.6	17.1	14.3
Post	14.3	20	2.8	11.4	14.3	37

3.3 Changes Over Two Semesters Of The SPQ Sub-Scale And Scale Scores

While the increase in those classified as adopting a Deep Approach and the decrease in those adopting an Achieving Approach is encouraging, the changes were only partially supported by changes in the sub-scale and scale scores of the SPQ. Group means were compared using the pairwise t-test and after the two semesters of instruction the Surface Motivation had increased, there was no change in the Deep Approach, Achieving Approach had decreased, and there were trends that point to a decrease in Deep and Achieving Motivations and Achieving Strategy. The results are presented in Appendix 2.

CHAPTER 4

Intellectual Demands Of Quizzes, Tests, And Final Examinations

4.0 Introduction

This chapter describes the results of the coding of the items of the quizzes, tests, and final examinations according to the taxonomy developed in this study.

4.1 Level Of Thinking Of The Assessment Items

The coding scheme developed classifies the level of thinking required by the assessment items into four hierarchical levels; Memory, for items remembered rather than solved; Procedural/Algorithmic, for problems of a routine nature; Procedural/Comprehension, for problems and items requiring limited comprehension or understanding; and Comprehension, for problems and items requiring understanding of principles and concepts, and non-routine translation from one representation to another such as from a table to a graph. No items were encountered at the higher levels of thinking: analysis, synthesis, or evaluation. While problem solving involves elements of each of these abilities, the conclusion of the researcher and the coders was that few of

the items were novel, and although many required considerable mathematical manipulation, the thinking demanded fell short of that required by the higher levels of Bloom's taxonomy. Of the 710 items from the thirty quizzes, fifteen term tests, and ten final exams, most (58%) were at the Procedural/Comprehension level, while 28.5% were at the Comprehension level, 12.7% were at the Procedural/Algorithmic level, and 0.8% of the items were coded at the Memory level, as shown in Figure 4.1.

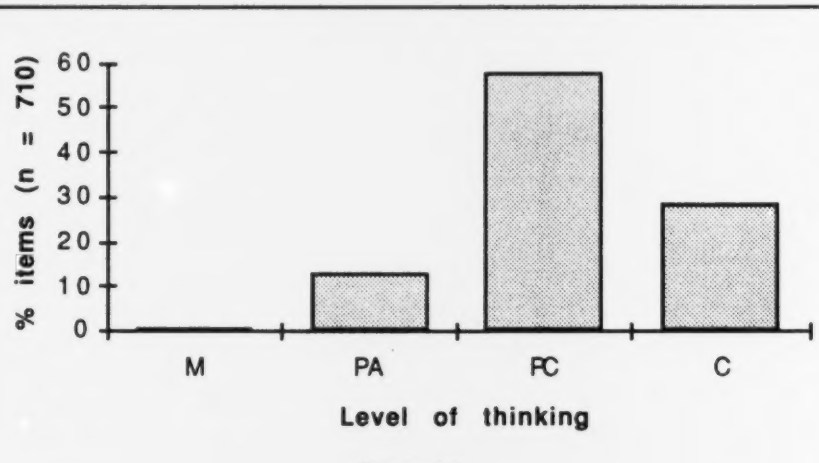


Figure 4.1

Percent Total Items By Level Of Thinking

4.2 Categories Of Assessment Items: Problem, Diagram, Graph, Written Response, Multiple Choice, Theory

The majority of the 710 items examined (75.9%) were problems. Just over ten percent required the construction or interpretation of a diagram; 6.7% required the construction or interpretation of a graph; 4.5% required a written description or explanation. There were 2.1% multiple

choice questions, and 0.4% of the items required the student to demonstrate a proof or develop a theoretical expression. The percentage of total items accounted for by each category is presented in Figure 4.2.

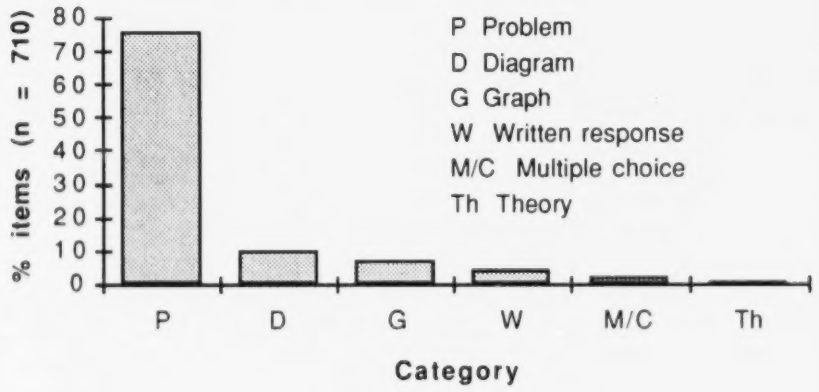


Figure 4.2

Percent Total Items By Category.

4.3 Level Of Thinking For Each Category

Most items were problems and these ranged from the most routine to the complex and mathematically challenging. Rehearsal tended to reduce the level at which a problem might otherwise have been coded. In fact two problems, both from course 301, and from two different colleges, were coded at the memory level because the coders considered that while it would be possible to "solve" the problem, students would be more likely to remember the answer. Of the 539 items classified as problems most (69.8%) were coded at the Procedural/Comprehension level, 15% at the Procedural/Algorithmic level, 14.8% at the Comprehension level, and 0.4% were coded at the Memory level, as shown in Figure 4.3.

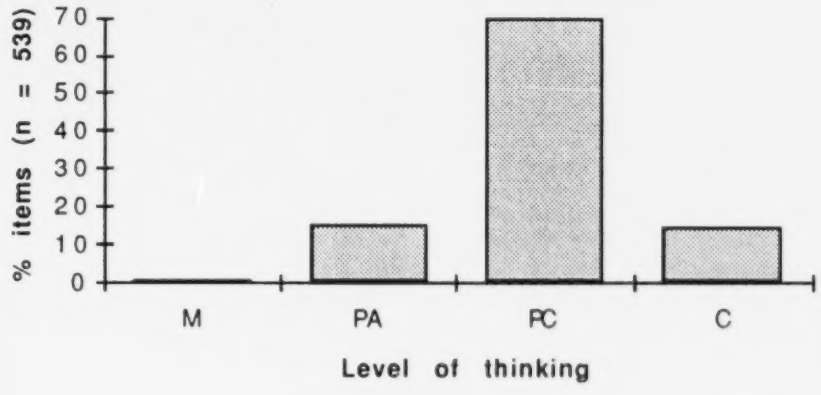


Figure 4.3

Percent Of Items Classified As Problems By Level Of Thinking

There were 73 items classified as diagrams and 48 items classified as graphs. For the 73 items classified as diagrams, 80% were coded at the Comprehension level, 16.4% at the Procedural/Comprehension level and 1.3% at each of the Procedural/Algorithmic and Memory levels. For the 48 items classified as "graphs," 37.5% were coded at the Comprehension level, 47.9% at the Procedural/Comprehension level, and 14.5% at the Procedural/Algorithmic level, as shown in Figure 4.4.

Thirty of the 32 items classified as requiring a written response were coded at the Comprehension level and two at the Memory level. The multiple choice items were found in one of the mechanics final exams and were based on questions from the Force Concept Inventory of Hestenes, Wells and Swackhamer (1992); fourteen of the 15 items were coded at the Comprehension level and one at the Memory level.

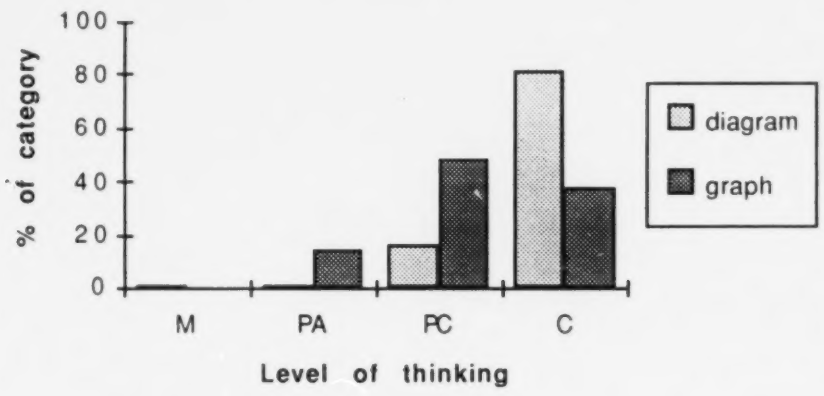


Figure 4.4

Percent Of Items Classified As Diagram And As Graph By Level Of Thinking

One of the three theory items was coded at the memory level and two at the Comprehension level. These three items were amongst the most difficult to obtain a consensus on: Were they remembered in a rote fashion, or understood? To what degree had they been rehearsed?

4.4 Level Of Thinking Of Items For Courses 101, 201, And 301

In all, 253 items of the course Mechanics 101 were coded, 236 items of Electricity and Magnetism 201, and 221 items of Waves and Optics 301. It was found that the percentage of items coded at the Comprehension level increased from 22.9% in course 101 to 30% in course 201 to 33% in course 301, and the percentage of items at the Procedural/Comprehension level underwent a corresponding decline from 64.8 to 57 to 51.5% respectively. The percentage of items coded at each level of thinking for each course is shown in Figure 4.5, and the complete data is given in Appendix 3.

While there is an increase in the percentage of items at the Comprehension level from course 101 to 201 to 301, and a corresponding decrease in items at the Procedural/Comprehension level, it should be remembered that no items were judged to require analysis, synthesis, or evaluation.

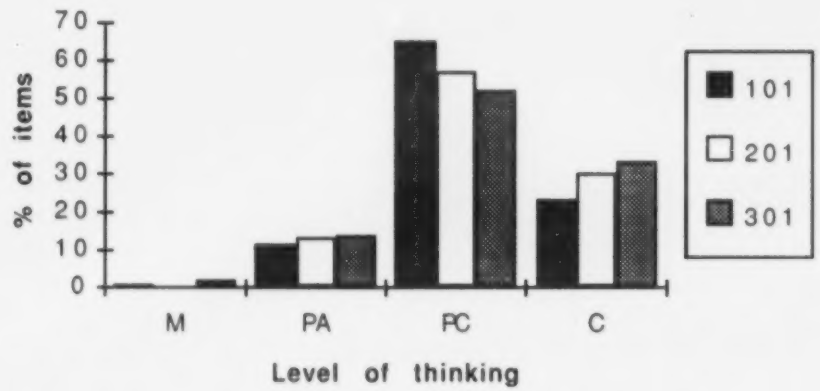


Figure 4.5

Percent Of Items By Course And Level Of Thinking

4.5 Level Of Thinking By Grade

To determine whether analyzing the level of thinking by number of items, rather than by grade assigned to each item, skewed the results, the grade assigned each item of the quizzes, tests, and final exams from John Abbott College for the winter semester 1994, was determined. It was found that in general teachers gave more weight to items coded at the higher levels of thinking and less weight to items coded at the lower levels. Results for the course Mechanics 101 showed that for those items coded at

the lower level of problem solving, Procedural/Algorithmic, the teachers grading the items assigned less weight, while those coded at the Procedural/Comprehension level were given more weight, and items coded at the highest level, Comprehension, were given slightly more weight as shown in Figure 4.6. This same pattern was found for courses 201 and 301. The complete data is given in Appendix 4.

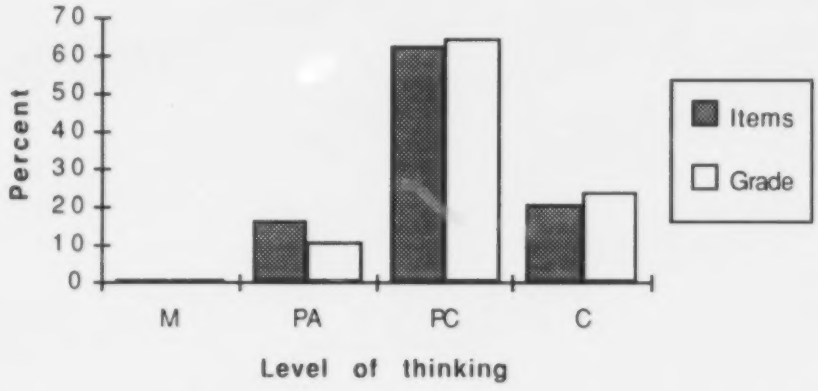


Figure 4.6

Course 101 John Abbott College Winter Semester 1994. Percentage Of Items At Each Level Of Thinking Compared With Percentage Of Grade Assigned To Each Level Of Thinking.

4.6 Level Of Thinking By Grade: Quizzes, Tests, and Final Examinations

The final grade in a course is made up of grades from the quizzes, tests, final examination, and the laboratories. This study was concerned with the thinking skills demanded by the quizzes, tests and final exams. The interplay between the levels of thinking demanded by an item, the

grade assigned the item, and the assessment type (exam, test, quiz) of the item, can be looked at in two ways: firstly, in terms of the percentage of the grade of each type of assessment (quiz, test, final) coded at each of the levels of thinking; and secondly, in terms of the absolute contribution to the final grade of items coded at each level of thinking for each type of assessment.

For the course Mechanics 101, it was found that the final exam contained a greater percentage of items coded at the Comprehension level than did the tests and quizzes, and a lower percentage of items at the Procedural/Algorithmic level: for all three types of assessment the greatest percentage of items were at the Procedural/Comprehension level, as shown in Figure 4.7. The complete data for all three courses is given in Appendix 5.

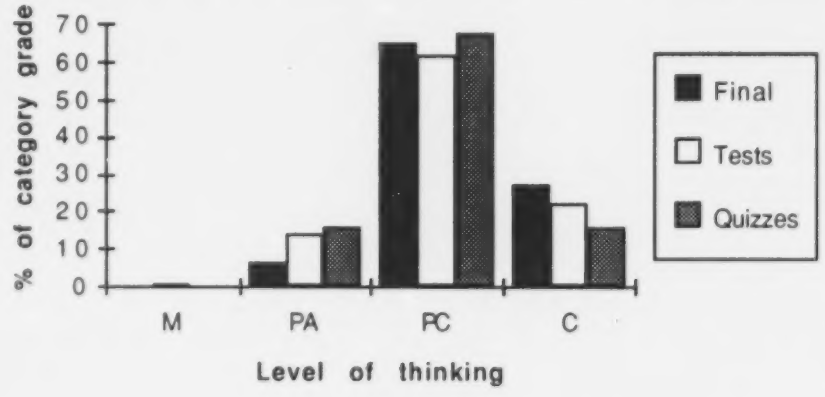


Figure 4.7

Course 101: Percentage Of The Grade Of Each Type Of Assessment Due To Each Thinking Level

For course Electricity and Magnetism 201 the percentages of each of the final exam, tests, and quizzes coded at each level were very similar: approximately 35% at the Comprehension level, just under 60% at the Procedural/Comprehension level and approximately 6% at the Procedural /Algorithmic level, as shown in Figure 4.8.

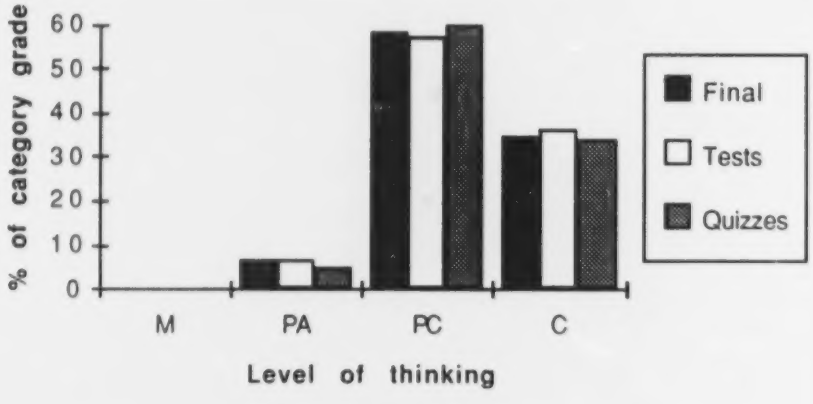


Figure 4.8

Course 201. Percentage Of The Grade Of Each Type Of Assessment Due To Each Thinking Level

For course Waves and Optics 301, the percentages of the final exam, tests, and quizzes at each of the levels of thinking was more varied than that of either 101 or 201, as shown in Figure 4.9.

For each course the final exam contributed 40 marks to the total grade while the tests contributed 30 marks and the quizzes just 10 marks (the remaining 20 marks came from the laboratory reports). Because of the predominance of grades assigned to the Procedural/Comprehension level examination of the absolute contribution by type of assessment did not reveal significant patterns.

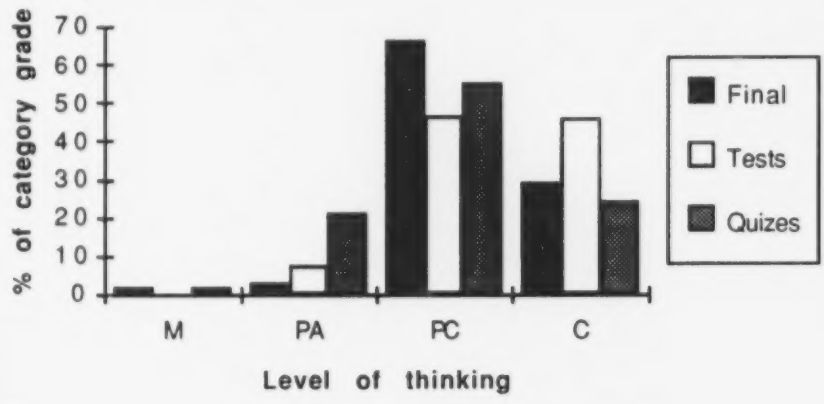


Figure 4.9

Course 301: Percentage Of The Grade Of Each Type Of Assessment Due To Each Thinking Level

Overall, the marks assigned to items at the Comprehension level increased from course 101 to 201 to 301, while the marks assigned to items at the Procedural/Comprehension level declined. At the lowest level of problem solving, Procedural/Algorithmic, more marks were assigned to items in course 101 than in either of the subsequent courses, and there was a very small number of marks given for memory items in courses 101 and 301, as shown in Figure 4.10.

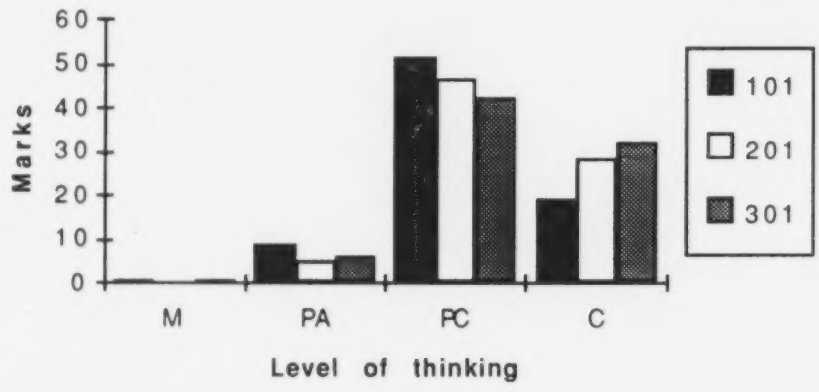


Figure 4.10

Grade By Course By Level Of Thinking: John Abbott College Winter Semester 1994

The increase in the grade due to items at the highest level of thinking encountered, Comprehension, as one goes from Mechanics 101 to Electricity and magnetism 201, to Waves and Optics 301, would seem to be appropriate but we must remind ourselves that the higher levels of thinking, analysis, synthesis and evaluation were not found.

CHAPTER 5

Approach To Learning, Intellectual Demands Of Assessment, And Performance

5.0 Introduction

This chapter reports the relationships between the approach to learning of the students as determined by the Study Process Questionnaire, the intellectual demands of the assessment tasks, and the performance of the students on the final exams and the Force Concept Inventory.

5.1 Approach To Learning Related To Assessment Performance

Significant links were found between the approach to learning adopted by students and their performances on both the Mechanics 101 and Electricity and Magnetism 201 final examinations. A step-wise linear regression of the scale scores of the SPQ, the Cote Final, and the Force Concept Inventory (the independent variables) with the Mechanics 101 final exam grade (the dependent variable), showed that high school performance, as measured by the Cote Final, was more strongly correlated to performance than the other measures and that both the FCI and Achieving Approach scores were positively correlated while the Deep Approach score had a negative correlation. Results are shown in Table 5.1.

Table 5.1

Step-Wise Linear Regression Mechanics 101 Exam Grade.
Squared Multiple R = 0.948
(n = 107)

Variable	Std Error	Std Coef	T	p
Cote Final	0.175	0.821	5.65	.000
Force Concept Inventory	0.608	0.275	3.67	.000
Deep Approach	0.392	-0.358	-2.37	.019
Achieving Approach	0.349	0.244	1.65	.102

High school performance was also more strongly correlated to performance on the Electricity and Magnetism exam than the other measures. A step-wise linear regression between the Cote Final, the FCI, and the scale scores of the SPQ (both measures being re-written at the end of the second semester) and the Electricity and Magnetism final exam grade showed that the Cote Final, the score on the FCI and the Achieving Approach score were positively correlated to performance, and Surface Approach score was nagatively correlated with performance.

There was a clear relationship between intellectual demands of the exam, performance on the exam, and approach to learning. The fall 1993 Mechanics 101 final exam had just 6.6% of its grade coming from items coded at the Comprehension level and there was a negative correlation between performance and Deep Approach. In contrast the winter 1994 Electricity and Magnetism exam had a much higher percentage, (34.8%) of its grade coming from items coded at the Comprehension level and there was a negative correlation between performance and Surface Approach. Results are shown in Table 5.2.

Table 5.2

Step-Wise Linear Regression Electricity And Magnetism 201 Exam Grade And Measures Written At The End Of The Second Semester
Squared Multiple R = 0.957
(n = 35)

Variable	Std Error	Std Coef	T	p
Cote Final	0.074	0.985	3.78	.001
Force Concept Inventory	0.177	0.313	2.93	.006
Surface Approach	0.142	-0.697	-2.84	.008
Achieving Approach2	0.134	0.382	1.76	.089

There were differences between the approach to learning of students who passed Mechanics 101 and those who failed. A one way analysis of variance for the initial sample showed that those who passed Mechanics 101 had a higher score on the Achieving Strategy sub-scale than those who failed. While there was no significant difference on the Achieving Motive sub-scale there was a strong trend ($p = .56$) for those who passed to have a higher Achieving Approach score. This finding is in agreement with the finding that the majority of the marks (91.7%) on the fall 1993 Mechanics final exam came from items coded at the Procedural/Comprehension level, i.e. the problems were straightforward and required only limited understanding of principles. The results are shown in Table 5.3.

There were also differences between the approach to learning of students who passed and failed Electricity and Magnetism 201. Because the number (35) was small a statistical analysis was not attempted but those who adopted Deep or Deep Achieving approaches were more successful than those who adopted a

Surface Approach. The students who participated in the second part of the study rewrote the SPQ during the last weeks of the semester shortly before the final examinations. Of the 35 students 22.8% (8) failed Electricty and Magnetism 201 and 77% (27) passed. For the 14% (5) who were classified as adopting a Surface Approach when they re-wrote the SPQ three failed and two passed: of the 20% (7) classified as adopting a Deep Approach 6 passed and 1 failed, in addition all of the 18% (5) classified as adopting a Deep-Achieving Approach passed, while three of the four classified as adopting a Surface-Achieving Approach passed: the one student classified as Achieving passed. These findings show that a Deep Approach to learning was associated with success in the course, and can be related to the 28.4% of the grade in the course coming from items at the Comprehension level and 46.5% from items at the Procedural/Algorithmic level.

Table 5.3

Univariate Analysis Of SPQ Sub Scale Score Achieving Strategy And Scale Score Achieving Approach.
(n = 107)

	Pass n = 93		Fail n = 14			
	Mean	S.D.	Mean	S.D.	T	p
SPQ sub-scale Achieving strategy	22.93	4.80	20.07	5.38	2.05	.04
SPQ Scale Achieving approach	48.68	7.21	44.36	11.16	1.94	.056

Pearson product-moment correlations were computed between students' grade on the Mechanics 101 final exam, and each of the scale and sub-scale scores of the SPQ. It was anticipated that there would be a positive relationship with deep and achieving scores and a negative relationship with surface scores. None

were found however. In addition there were no significant correlations between performance in the 101 final exam and the SPQ scales and sub-scales for the cohort of 35 students who, after successfully completing Mechanics 101, went on to follow Electricity and Magnetism 201. However there was a significant negative relationship ($p = .51$) between Surface Approach and grade in the 201 final examination. The results are shown in Appendix 6.

5.2 Approach To Learning And Score On The Force Concept Inventory

The incoming students wrote the SPQ and the FCI at the start of their first semester. For these students, the ones who were classified as adopting a Deep Approach to learning scored significantly higher on the Force Concept Inventory than did the others. A Tukey HSD multiple comparison showed that the group classified as adopting a Deep Approach to learning scored significantly higher than those classified as adopting either a Surface ($p = .012$) or an Achieving ($p = .001$) Approach. In addition those classified as Deep scored significantly higher than those classified as either Deep Achieving ($p = .005$), or Surface Achieving ($p = .003$). None of the other between-groups differences were significant. All of the students classified as adopting a Surface Approach had FCI scores lower than that of the lowest score of the students classified as adopting a Deep Approach. Results are shown in Tables 5.4 and 5.5.

Table 5.4

Means And Standard Deviations For Score On Force Concept Inventory By Approach To Learning

	Approach				
	Surface	Deep	Achieving	Surface Achieving	Deep Achieving
	n=13	n=6	n=15	n=31	n=13
FCI (%)	46.4	70.1	46.9	47.1	48.7
S.D.	10.9	10.8	13.0	14.2	13.8

Table 5.5

Analysis Of Variance For Approach To Learning And FCI Score

	df	SS	MS	F	p
Between groups	5	349.5	69.90	4.08	.002
Within-groups	101	1729.1	17.12		

The relationship between the Deep Approach and the score on the FCI is consistent with the aims of the two measures. A Deep Approach indicates an intention to apply principles to real-world problems and the FCI is known to test conceptual understanding of Newton's laws and the ability to apply the concepts to realistic situations. From Table 5.4 the mean score of the group of students identified as adopting a deep approach is 70%. The significance of this score can be gauged by the average pretest scores reported by Hestenes, Wells, and Swackhamer (1992) of between 34% and 52% for students entering university, and posttest averages of between 63% and 68%, and in the case of a posttest conducted in a class consisting mostly of physics majors at Harvard, 77%. The SPQ is identifying those incoming students who have a very good conceptual understanding of Newton's laws of motion.

5.3 Relationships Between Study Process Questionnaire Scale And Sub-Scale Scores, And Score On The Force Concept Inventory

The FCI and the SPQ were written at the beginning and again at the end of the study. For both sets of data Pearson product-moment correlations were computed between students' scores on the FCI and each of the scales and sub-scales of the SPQ. There were significant negative relationships between FCI score and an Achieving Approach for the pretest results and between FCI score and both an Achieving Approach and a Surface Approach for the posttest results. The findings suggest that the students did not adapt their approach to the demands of the Force Concept Inventory (which requires conceptual understanding rather than rote application of Newton's laws). The results are given in Appendix 7.

5.4 Changes In The SPQ Scale And Sub-Scale Scores And The FCI Score After Two Semesters Of Instruction

For the cohort of students who re-wrote the measures at the end of the second semester, group means were compared using the pairwise t-test. Over the course of the two semesters the Surface Motivation increased. There were trends that point to a decrease in Deep and Achieving Motivation and Achieving Strategy, and a significant decrease in Achieving Approach. These findings when taken together with the finding that almost two-thirds of the marks in the final exams for both the Mechanics and the Electricity and Magnetism courses came from items coded at the routine levels of problem solving support the notion that the demands of assessment determine the type of learning. If the assessments do not encourage thinking students will adopt a surface approach.

The increase in the score on the FCI over the two semesters was significant: the increase of 12.3% was in agreement with increases reported by Hake (1994) for conventional instruction. Results are presented in Appendix 8.

5.5 Relationship Between Performance And Score On The FCI And The Cote Final

Pearson product-moment coefficients of correlation showed significant correlations between the performance on the Mechanics final exam and high school performance, as measured by the Cote Final, and prior knowledge, as measured by the FCI. For the sample which re-wrote the measures at the end of the second semester there were significant correlations between performance in the Electricity and Magnetism exam and the Cote Final, as well as substantial correlations between performance in the exam and the FCI scores obtained both when the measure was written on entry to the college and when it was re-written at the end of the second semester. The results are given in Appendix 9.

5.6 Relationships Between Gender And Performance On The Final Examinations, The FCI And The SPQ

Given the different persistence and success rates of male and female John Abbott science students reported by Boisset, MacKenzie and Sidorenko (1989) and the more recent study of Davis and Steiger (1993) on gender neutral instruction in Cégep physics courses, the results were examined for gender differences. The initial sample of 107 consisted of 38 females and 69 males; the follow-up sample of 35 students consisted of 13 females and 22 males. There were no significant differences in the scores of males and females on the scales and sub-scales of the

SPQ. Significant differences were found in the Cote Final, and the FCI scores. Initially the females in the sample of 107 entered the college with higher Cote Final scores than the males, but scored lower on the FCI. At the end of the first semester there were no significant differences between the Mechanics 101 exam scores of males and females. For the cohort of 35 who proceeded directly from Mechanics to Electricity and Magnetism there was no significant difference between the Cote Final scores of males and females; the Cote Final scores of the males who persisted were higher than those in the initial sample as a whole. The male students maintained their higher score on the FCI when the measure was re-written at the end of the second semester. There was no difference in the Electricity and Magnetism exam mark of males and females, but the males who persisted had scored higher on the Mechanics final exam than had the females who persisted. The results are shown in Tables 5.6 and 5.7.

Table 5.6

Univariate Tests For Measures
Cohort Of 107

	Male (n = 69)		Female (n = 38)			
Measure	Mean	S.D.	Mean	S.D.	T	p
Cote Final	92.1	11.8	100.5	10.6	3.62	<.000
Force Concept Inventory %	51.2	14.8	38.4	12.4	4.5	<.000
Phys 101 exam %	73.6	22.6	73.9	20.4	0.06	n.s.

Table 5.7

Univariate Tests For Measures
Cohort Of 35

Measure	Male (n = 22) Mean	S.D.	Female (n = 13) Mean	S.D.	T	p
Cote Final	99.7	9.4	104.0	11.4	1.21	n.s.
Force Concept Inventory(pre)%	56.1	16.9	40.8	13.4	2.78	.009
Phys 101 exam %	89.6	7.9	79.7	17.8	2.24	.03
Force Concept Inventory(post) %	64.6	20.4	43.5	10.5	3.45	.002
Phys 201 exam %	71.94	14.4	64.2	28.9	1.05	n.s.

Other recent studies have found that male students achieved higher scores on the FCI than female students (Flood, Cross & Snodgrass, 1994; Blue and Heller, 1994). Heller has speculated that possible causes for the lower scores of females on the inventory is that females frequently do worse than males on multiple choice tests because they tend to see nuances of meaning and are not prepared to guess in the way males are, and that the classroom climate of high school, where boys are asked more questions and the answers of girls are often not recognized or valued, inhibits females from achieving a good understanding of the concept of force (Heller, private communication 1994; Jones and Wheatley, 1990). Another possible cause is that boys frequently have more experience than girls in pushing, throwing, and playing with erector sets and mechanical toys.

CHAPTER 6

Discussion

6.0 Introduction

This exploratory study asked three questions: first, what were the approaches to learning adopted by physics students; second, what were the intellectual demands of assessment in physics; and third, were there links between the approach to learning, the demands of the assessment tasks and the performance of the students. In this chapter the findings are summarized, some implications for teaching and learning explored, some questions posed, and extensions to this study suggested.

6.1 Summary Of The Findings

6.11 Approach To Learning

This study found that incoming physics students approach physics with the intention of memorizing formulae rather than understanding concepts, they adopt Surface or Surface-Achieving Approaches. Those students who proceeded directly from the first to the second physics course, i.e. those who were academically on-track, showed a predominantly Achieving or Surface-Achieving approach on entering the college and by the end of two semesters

of instruction the percentage of those adopting an Achieving Approach had declined while the percentage adopting Surface and Deep Approaches had increased. The decline in the percentage classified as adopting an Achieving Approach, from 31.4% to 2.8%, was as marked as the increase in the Deep Approach, from 2.8% to 20%, while the increase in the Surface Approach was from 5.7% to 14.3%.

Are the motives and strategies that students adopt the ones that teachers consider desirable? If instruction is to be effective it must be aware of, and understand, the preconceptions students hold about both the content and the learning task in physics. How should teachers use this information to counsel students and to guide the form of instruction to better match instruction to the beliefs and practices of incoming students, and to the goals they, as teachers, consider desirable?

6.12 Intellectual Demands Of Assessment Items

The majority of the items of the quizzes, tests, and final exams required routine problem solving. For the final examinations of the winter semester 1994 the percentage of the grade requiring comprehension increased from Mechanics 101 (19%) to Electricity and Magnetism 201 (28%) to Waves and Optics 301 (32%) and the percentage of items requiring routine problem solving declined. No items were coded at the higher levels of Bloom's taxonomy (analysis, synthesis, evaluation). Does the physics community consider that the levels of thinking demanded by these courses are appropriate? Should assessment in physics require students to demonstrate analysis, synthesis, and evaluation?

A limitation of the present study was that the cognitive level of laboratory work was not addressed. In writing a laboratory report are students required to complete a table, or to synthesize data, theory and results? Are the levels of thinking that were absent from the quizzes, tests and final examinations required of students as they carry out and report the results of the experiments they undertake?

6.13 Relationships Between Demands of Assessment, Approach To Learning, And Performance

The findings show that the performance of the students on the final examinations was related to the approaches to learning adopted by the students. The approach to learning adopted was, in turn, related to the cognitive demands of the assessments. In addition there were relationships between the prior knowledge of the concept of force and approach to learning adopted.

6.2 Links Between Persistence, Performance And Approach To Learning

Previous studies have shown that in post secondary science education Surface Approach increases and Deep Approach decreases due to the pressures of too little time to adequately deal with the amount of content and the pace of presentation of material. Concomitantly the research data shows that a Deep Approach is related to academic success (Biggs, 1987).

Teachers must respond to many influences. The students in the study entered the college as the new science program was being introduced. For the first time most students were entering Mechanics 101 rather than

Introductory Physics 111. The instructors were grappling with finding the proper level for the course and were very concerned with the demands of the course both in terms of the amount of material covered and in terms of the level of difficulty of the course. Their solution was to develop quizzes, tests, and a final examination that were in their view straightforward. The cognitive demands of the final examination were low. Over 90% of the questions involved routine problem solving and just 6% required comprehension. Seventy seven percent of those who persisted and wrote the Mechanics 101 final examination passed. When the successful students entered Electricity and Magnetism 201, they were faced with what many consider to be the most challenging of the three physics courses (in many Cégeps 201 is taught after 301 because of this). The quizzes, tests, and the final examination had a much higher fraction of items that required comprehension. Correspondingly a higher percentage of those who persisted and were successful adopted a Deep Approach.

The influence of the demands of assessment on the approach to learning adopted by the students was further illustrated by the results of the step-wise linear regression between grade in the final exam and cognitive demands of the exam. There was a negative correlation between Deep Approach and the grade in the Mechanics 101 final exam. This can be related to over 90% of the items requiring routine problem solving and just 6% requiring comprehension. For Electricity and Magnetism 201, there was a negative correlation between Surface Approach and grade in the final exam and this can be related to the 30% of items on the exam requiring comprehension.

When Pearson product-moment coefficients of correlation were calculated between the sub-scale and scale scores of the SPQ and grades in the

Mechanics 101 and the Electricity and Magnetism 201 final examinations, a negative correlation was found between grade in the Electricity and Magnetism 201 final examination and Surface Approach. However there were no significant relationships between the Mechanics 101 grade and the SPQ scores.

6.3 Understanding Of The Concept Of Force And Approach To Learning

The goal of most students is to pass and students adapt and adopt practices that they hope will ensure their success, however success in a course does not ensure understanding of the material covered. It is accepted that the Force Concept Inventory measures understanding of the Newtonian concept of *force*. Over the two semesters the students who persisted showed a gain of 12% in their score on the FCI. This increase is in agreement with that reported in the literature for conventional physics courses, but is much less than has been achieved by more interactive courses (Hake, 1994). Such courses engage the student in tasks that require active participation and the use of higher level thinking skills. The findings of this study that show a negative relationship between both Surface and Achieving Approach and prior knowledge, as measured by score on the FCI, are in agreement with other work in psychology (Beckwith, 1991).

6.4 Conclusion

The findings of this work suggest that the intellectual demands of assessment tasks influence the approach to learning adopted by students. Classroom assessment guides learning. A majority of the questions in the

quizzes, tests, and final examinations required problem solving with some limited understanding of the principles and concepts. It would be possible to pass the courses without understanding the concepts. One can infer that the students are acquiring content knowledge but must ask if they are able to apply this knowledge to complex, unfamiliar situations.

6.5 Possible Extensions And Questions For Physics Teachers To Consider

If we are to fully determine the thinking skills developed by current instructional practices then as a first step the intellectual demands of laboratory work must be determined. Secondly, after designing and testing assessment tools that develop higher levels of learning, a study that compared the learning outcomes of a control group and a group of students that was exposed to assessment that required higher levels of intellectual engagement would allow one to explore more fully the links between assessment, approach to learning, and performance. Finally, this work has shown the relationships that exist between assessment and approach to learning for students who persist and succeed, it does not answer directly the questions that arise about the relationships between approach to learning and assessment for those who drop out and fail. Such a study could help teachers give appropriate guidance, and design appropriate instruction to help those who currently fail.

What is known is that involving students with the tasks rather than encouraging silent listening or repetitive calculations does achieve increased understanding. However if time is to be devoted to allowing students to grapple with the ideas then the content covered must be reduced. (However we must ask if the content was covered by the student or by the teacher.)

A constant debate among Cégep physics teachers is what topics to include and what to omit as they see themselves squeezed between the high schools and the universities and buffeted by the changes in curriculum and course structures dictated from above. Many traditional practices of teaching and assessment are no longer appropriate for the diverse population that fills present day physics classrooms. The background, outlook, and needs of students have changed. Society no longer accepts without question the value of physics as an intellectual discipline and as a subject that can provide solutions to societal problems. Faced with these challenges physics teachers must re-examine their teaching and assessment methodologies and adopt strategies that will encourage meaningful learning of the mix of content and process they, the teachers, consider appropriate. What changes, if any, to current methods of teaching and assessment will ensure that students combine knowledge of current content and concepts with the ability to apply these in meaningful ways, and the ability to adapt to as yet unknown challenges and ideas?

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Appendix 1: Taxonomy For Coding The Intellectual Demands Of Physics Assessment Items

1 MEMORY Recalling information much as it was learned.

1.1 Memory requires the recall or recognition of specific elements in a subject area in a way similar to how it was learned. In its simplest form this includes recalling the terminology and specific facts associated with an area of subject matter.

1.2 At a more complex level it means knowing the the major sub-areas, methods of inquiry, classifications and ways of thinking characteristic of the subject area, as well as the central theories and principles.

Examples:
(a) Define work.
(b) State Newton's three laws of motion.

2 PROCEDURAL/ALGORITHMIC Routine calculations

2.1 Items requiring the student to apply a single principle or to apply a predictable formula or algorithm (that requires no choices)to generate an answer. The problem is familiar and the rule or principle is either given in the problem or very familiar from previous rehearsal.

2.2 Items requiring the student to make a simple interpretation of data. Such as read a coordinate from a graph.

Examples
(a) If a force of 10N acts on a mass of 6kg what is the acceleration?
(b) What are the X and Y components of a displacement of 6m at an angle of 40° to the X axis?
(c) If $Q = Qo\,(1 - e^{-t/RC})$ where $R = 100\Omega$, $C = 4.7\mu F$, and $Qo = 4.5mC$, what is the charge on the capacitor after 8.0s?
(d) Given a position time graph: What is the position at $t = 4s$?

3 PROCEDURAL/COMPREHENSION Problem solving with limited comprehension

3.1 Solving a problem that requires that choices be made about which rule or principle to apply based on the information given in the problem. The situation is familiar. The problem involves a familiar pattern, and problems of similar type have been rehearsed either in class, during quizes or tests, or in assignments.

3.2 Items requiring the student to make straightforward interpretations of data requiring some limited judgement. Such as construct the tangent at a point on a curved position-time graph and take the slope to find the instantanous velocity. Produce a routine free body diagram.

Examples

(a) A dog is running at a constant velocity of 4.0m/s towards a cat. When the dog is 16.0m behind the cat the cat starts accelerating from rest at $0.30 m/s^2$. When and where does the dog catch up with the cat?

(b) A block of mass 5.0kg rests on a smooth horizontal surface. A force of 4.0N acts parallel to the surface. Construct the free body diagram of the block.

(c) Given a curved position time graph. Find the instantaneous velocity at some given time.

4 COMPREHENSION Reporting information in a way other than which it was learned in order to demonstrate that it has been understood. Apply a rule or principle in such a way as to demonstrate not only the application of the rule but an understanding of why the application is appropriate.

4.1 State a principle and give an example of its application. Describe properties, units, vector/number, typical magnitudes.

4.2 Interpret a principle in different ways: symbols, words, graphs, numbers.

4.3 In a physical situation identify those relations which are applicable and use them without confusion.

Comprehension continued
Examples:

(a) Given a data table of y(t) for a ball thrown into the air construct the velocity time graph.

(b) Given a velocity time graph having a changing velocity, construct the position time graph.

(c) A boat is sailing on Lac St Louis with a velocity of $\mathbf{v}_1$ = (5m/s, 323°), ten minutes later it has a velocity of $\mathbf{v}_2$ = (- 6.0, 2.0)m/s. Sketch, not to scale, the vector triangle showing the vectors $\mathbf{v}_1$, $\mathbf{v}_2$, and $\Delta\mathbf{v}$.

(d) A singly charged positive ion, mass, 2.5×10^{-25}kg, enters at right angles to a uniform magnetic field with magnitude $B = 5.0 \times 10^{-2}$T. What must be the magnitude of the perpendicular electric field, E, which would allow the ion to pass through without being deflected? Include a diagram showing the relative orientations of $\mathbf{v}$, $\mathbf{B}$, $\mathbf{E}$, $\mathbf{F}_{mag}$, $\mathbf{F}_e$.

(e) A car is driving around a banked curve (r = 1000m, angle 7°) The coefficient of kinetic friction between the road and the tires is 0.4 and the car is driven at the maximum posible speed without slipping sideways. Draw the free body diagram of the car.

5 ANALYSIS Taking learned information apart.

5.1 Analysis refers to logic, induction, deduction, and formal reasoning: it is the breakdown of a problem into its constituent ideas or parts so that the relative hierachy of the ideas is made clear and/or the relations between the ideas is made explicit.

5.2 Learning outcomes represent a higher intellectual level than comprehension because they require an understanding of not only the content and the structural relationships of the material but the ability to apply this knowledge to a new, unfamiliar, situation. The learner must be able to identify the important elements in a problem, determine the connections between the parts, then recognize the stucture and principles that connect the situation.

5.3 The student is asked to distinguish, classify, and relate the assumptions, hypotheses, data, conclusions and structure of the question.

6 SYNTHESIS — Create a product that is new. Draw together elements and parts to form a whole that is new.

6.1 Synthesis is the putting together of elements and parts to form a whole. This involves arranging and combining pieces in such a way as to create a structure that was not there before.

6.2 Students create, integrate, and combine ideas and data into a product that is new to them.

7 EVALUATION — Judging the value of something for a particular purpose. Use of a standard of appraisal. The criteria may be determined or given. Evaluation has two steps. The first is to set up appropriate standards(criteria) and the second is to determine how closely the object or idea meets these standards.

7.1 Evaluation of the accuracy of ideas, works, solutions, methods or material, from logical accuracy, consistency or other internal criteria.

7.2 Evaluation of material with respect to remembered or specified criteria. Evaluation requires that the student makes judgements about something he or she knows, analyses, synthesizes, and so forth, on the basis of criteria which can be made explicit.

Appendix 2: Univariate Analysis Of SPQ Sub-Scale And Scale Scores (n = 35)

	Pre		Post			
	Mean	S.D.	Mean	S.D.	T	p
SPQ sub-scales						
Surface motive	24.54	4.22	26.26	4.46	2.09	.04
Surface strategy	22.43	3.89	23.06	4.07	0.98	n.s.
Deep motive	22.74	4.24	21.17	5.23	1.72	.09
Deep strategy	22.17	3.87	22.17	3.85	0	n.s.
Achieving motive	26.17	3.83	24.82	5.38	1.96	.05
Achieving strategy	22.57	5.04	21.11	5.79	1.83	.07
SPQ Scales						
Surface approach	46.97	7.59	49.31	7.43	1.78	.08
Deep approach	44.91	6.83	43.34	7.51	1.16	n.s.
Achieving approach	48.74	7.51	45.94	9.64	2.26	.03

Note The SPQ was written at the start of the first semester (pre) and the end of the second semester (post).

Appendix 3: Percent Of Items By Course And Level Of Thinking

	Level of Thinking			
Course	Memory	Procedural/ Algorithmic	Procedural/ Comprehension	Comprehension
101	0.8	11.5	64.8	22.9
201		13	57	30
301	2	13.5	51.5	33

Note The items are expressed as as a percentage of the number of items in each course;

Course 101 253 items coded
201 236 items coded
301 221 items coded

Appendix 4: Percentage Of Items And Percentage Of Grade By Level Of Thinking: John Abbott College Winter Semester 1994

		Level of Thinking			
	Course	Memory	Procedural/ Algorithmic	Procedural/ Comprehension	Comprehension
	101	0.67	16.1	62.4	20.8
Items	201		11.2	54.3	34.4
%	301	1	22.3	42.7	33.9
	101	0.32	8.5	51.6	19.2
Grade	201		5.2	46.5	28.4
%	301	0.2	5.8	42.2	32

Notes (a) The marks are expressed as a percentages of the grade of 100 that was assigned to the course. The quizzes, tests, and final contributed 80% of the grade.
(b) The items are expressed as as a percentage of the number of items in each course;

Course 101 148 items coded
201 116 items coded
301 103 items coded

Appendix 5: Contributions Of Quizzes, Tests, And Final Examination To Grade By Level Of Thinking

			Level of thinking			
Course			Memory	Procedural Algorithmic	Procedural Comprehensio n	Comprehension
	Quiz	(10)		1.6	6.8	1.6
101	Tests	(30)	0.3	4.2	18.6	6.7
	Final	(40)		2.6	26.2	10.9
	Sum	(80)	0.3	8.5	51.6	19.2
	Quiz	(10)		0.5	6.0	3.4
201	Tests	(30)		2.0	17.2	10.9
	Final	(40)		2.6	23.2	13.9
	Sum	(80)		5.2	46.5	28.3
	Quiz	(10)	0.2	2.1	5.5	2.4
301	Tests	(30)		2.3	13.9	13.8
	Final	(40)		1.5	22.8	15.8
	Sum	(80)	0.2	5.9	42.2	32.0

Appendix 6: Pearson Product-Moment Coefficients Of Correlation Between SPQ Sub-Scales And Scales And Physics 101 And 201 Final Examination Grades

	Physics 101 (n = 107)		Physics 101 (n = 35)		Physics 201 (n = 35)	
	grade	p	grade	p	grade	p
SPQ sub-scales						
Surface motive	0.098		-0.056		-0.289	
Surface strategy	0.067		-0.091		-0.292	
Deep motive	0.010		0.054		0.056	
Deep Strategy	-0.044		0.061		-0.131	
Achieving motive	0.124		0.049		0.181	
Achieving strategy	0.070		0.145		0.035	
SPQ Scales						
Surface approach	0.094		-0.078		-0.333	.51
Deep approach	-0.019		0.068		0.028	
Achieving approach	0.113		0.122		0.087	

Appendix 7: Pearson Product-Moment Coefficients Of Correlation Between SPQ Sub-Scale And Scale Scores And Score On The FCI

	Pretest (n = 107)		Pretest (n = 35)		Posttest (n = 35)	
	score	p	score	p	score	p
SPQ sub-scales						
Surface motive	- 0.107		-0.095		- 0.296	.08
Surface strategy	- 0.124		-0.314	.06	- 0.477	.004
Deep motive	0.034		-0.049		-0.052	
Deep Strategy	0.114		0.204		0.061	
Achieving motive	- 0.217	.02	-0.194		- 0.184	
Achieving strategy	- 0.313	< .001	-0.349	.04	- 0.468	.005
SPQ Scales						
Surface approach	- 0.128		-0.214		- 0.438	.008
Deep approach	0.084		0.085		-0.005	
Achieving approach	- 0.318	< .001	-0.333	.05	- 0.384	.02

Notes: Probabilities not shown are not significant.
Physics 101 results are for the SPQ written at the start of the first semester
Physics 201 results are for the SPQ written at the end of the second semester
Pretest results are for the SPQ and FCI written at the start of the first semester
Posttest results are for the SPQ and FCI written at the end of the second semester

Appendix 8: Univariate Analysis Of FCI And SPQ Sub-Scale And Scale Scores (n = 35)

	Pre		Post			
	Mean	S.D.	Mean	S.D.	T	p
SPQ sub-scales						
Surface motive	24.54	4.22	26.26	4.46	2.09	.04
Surface strategy	22.43	3.89	23.06	4.07	0.98	n.s.
Deep motive	22.74	4.24	21.17	5.23	1.72	.09
Deep strategy	22.17	3.87	22.17	3.85	0	n.s.
Achieving motive	26.17	3.83	24.82	5.38	1.96	.05
Achieving strategy	22.57	5.04	21.11	5.79	1.83	.07
SPQ Scales						
Surface approach	46.97	7.59	49.31	7.43	1.78	.08
Deep approach	44.91	6.83	43.34	7.51	1.16	n.s.
Achieving approach	48.74	7.51	45.94	9.64	2.26	.03
FCI %	50.4	17.2	56.7	20.0	3.416	.002

Appendix 9: Pearson Product-Moment Coefficients Of Correlation Between High School Performance (Cote Final), Prior Knowledge (FCI), And Physics 101 And 201 Final Exam Grades

	Physics 101 (n = 107)		Physics 101 (n = 35)		Physics 201 (n = 35)	
	grade	p	grade	p	grade	p
CF	0.511	.000	0.306	.07	0.461	.000
FCI1	0.311	.001	0.437	.009	0.370	.03
FCI2					0.391	.02

Note FCI1 measure written at the start of the first semester.
FCI2 measure written at the end of the second semester.